Zeigler, K.E., Heckert, A.B., and Lucas, S.G., eds., 2003, Paleontology and Geology of the Snyder Quarry, New Mexico Museum of Natural History and Science Bulletin No. 24.

THE UPPER TRIASSIC (NORIAN: REVUELTIAN) SNYDER QUARRY, CHAMA BASIN, NORTH-CENTRAL NEW MEXICO: AN OVERVIEW

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This bulletin is the result of five years of excavation and research that centered on a remarkable Late Triassic bonebed, the Snyder quarry, in the Chama basin of north-central New Mexico. The Snyder quarry is stratigraphically high in the Petrified Forest Formation of the Chinle Group (Fig. 1), and tetrapod biostratigraphy places it in the later part of the Revueltian land-vertebrate faunachron (approximately mid-Norian in age: 210-215 Ma). A wide range of papers have been compiled here that document the discoveries from this locality, and this article is a summary of the various facets of research on the Snyder quarry.

Following Mark Snyder's discovery of NMMNH locality 3845, the "Snyder quarry," in June, 1998, five major and several minor excavations at the quarry were conducted, from July, 1998 to May, 2001, that recovered more than 60 jackets and hundreds of isolated elements (Heckert and Zeigler, 2003). After the famous Ghost Ranch *Coelophysis* quarry, this quarry is probably the richest single Chinle bonebed, as it yields more specimens per square meter than the contemporaneous Canjilon quarry or, indeed, any other quarry for which detailed excavation records exist.

In terms of lithostratigraphy, Triassic strata in the Chama basin pertain to the Upper Triassic Chinle Group (in ascending order, the Zuni Mountains, Shinarump, Salitral, Poleo, Petrified Forest and Rock Point formations) (Lucas et al., 2003b). The local base of the Chinle Group is the Zuni Mountains Formation (formerly "mottled strata"), a pedogenic weathering profile, developed in the top of the Pennsylvanian-Permian Cutler Group. Where the Zuni Mountains Formation is absent, the base of the Chinle Group is the Shinarump Formation, which also locally overlies the Zuni Mountains Formation. In the Chama basin, the Shinarump Formation (= Agua Zarca Formation of previous usage) is primarily trough-crossbedded, quartzose sandstone and siliceous conglomerate. The Salitral Formation is a mostly greenish and reddish brown, smectitic mudstone that is divided into two members named in this volume: a lower, Piedra Lumbre Member of greenish mudstone with a peristent sandstone bed (the El Cerrito Bed, named here) at its top, and an upper, Youngsville Member, mostly reddish-brown mudstone. The Poleo Formation is mostly grayish yellow, trough-crossbedded litharenitic and subarkosic sandstone with minor amounts of both intrabasinal and siliceous conglomerate. Above the Poleo Formation, the thickest of the Chinle Group units is the predominantly reddish brown, smectitic mudstone of the Petrified Forest Formation. In the Chama basin, the Petrified Forest Formation consists of two members, the lower Mesa Montosa Member (named in this volume), thin-bedded sandstone, siltstone and mudstone, which is overlain by the mudstone-dominated Painted Desert Member. The Rock Point Formation is mostly laterally persistent, repetitive beds of reddish brown and grayish red siltstone and ripple-laminar sandstone that disconformably overlie the Petrified Forest Formation.

Unionid bivalves from the Petrified Forest Formation suggest a Revueltian age, and palynomorphs from the Rock Point Formation are of Norian age. Three formations of the Chinle Group in the Chama basin contain biochronologically important vertebrate fossils, notably the aetosaur *Desmatosuchus haplocerus* (Adamanian) in the Salitral Formation, the aetosaurs *Typothorax coccinarum* and *Desmatosuchus chamaensis* and the phytosaur *Pseudopalatus* (Revueltian) in the Petrified Forest Formation, and the phytosaur *Redondasaurus* (Apachean) in the Rock Point Formation. These fossils and lithostratigraphy allow precise correlation of the Chinle Group strata exposed in north-central New Mexico with other Upper Triassic strata in New Mexico (Lucas et al., 2003b).

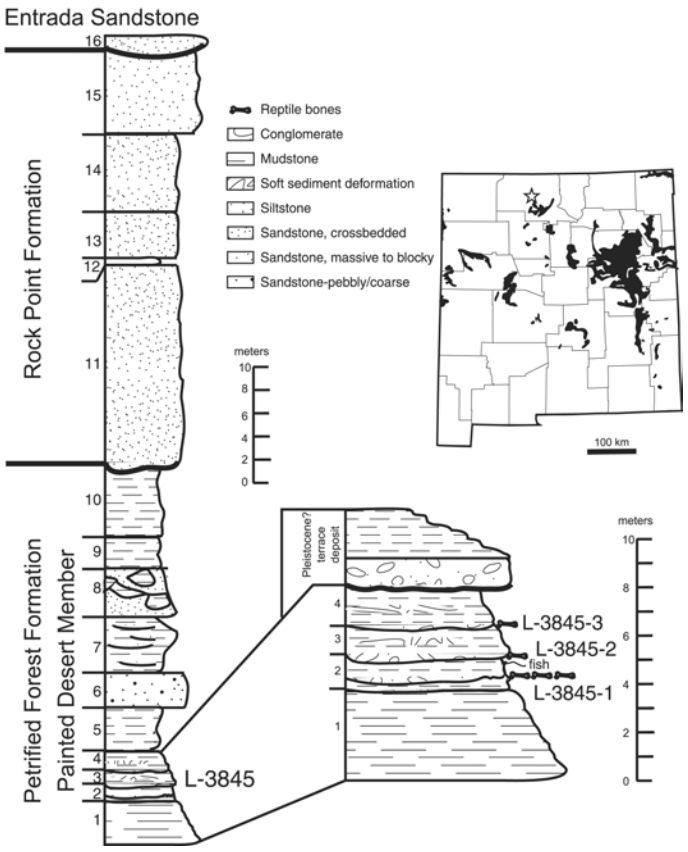

FIGURE 1. Index map showing location of the Snyder quarry site in north-central New Mexico, distribution of Triassic outcrops, and a stratigraphic section at the quarry.

A more detailed sedimentary petrographic study of the Snyder quarry strata revealed clues to the deposition of the bonebed (Tanner et al., 2003). Strata of the Petrified Forest Formation at the Snyder quarry comprise mudstones and intraformational conglomerates and the depositional setting of these strata was a broad, low-gradient flood basin. Mud was deposited by sheetfloods on flats and in standing water during intervals of basin aggradation. Clast-supported conglomerates interbedded with the mudstones comprise intraclasts of carbonate mudstone, micrite, and mudstone rip-ups deposited in shallow, low-sinuosity streams. The bulk of the bedload may have been formed by pedogenic reworking of carbonate sediments deposited in shallow ponds. Falling base level caused modest fluvial incision and reworking of the carbonate deposits. The primary bone-bearing layer is a matrix-supported conglomerate interpreted as the deposit of a hyperconcentrated flood that swept animal remains and downed trees into topographic lows.

The bulk of the labor, both in terms of excavation and research was directed towards understanding how the bonebed formed (Zeigler, 2003). It is unusual to have localities as rich in vertebrate material as the Snyder quarry. The site has yielded the remains of a wide variety of organisms, ranging from terrestrial and aquatic vertebrates to aquatic invertebrates, as well as a substantial amount of charcoalized wood. A

taphonomic analysis of both the biological material and the associated sediments indicates that the bonebed is the result of a catastrophic mass mortality event. The sediments of the bonebed contain moderately-rounded rip-up clasts from the surrounding floodplain, a significant portion of the bone and wood is aligned, there is a high density of bones over a large area, and a moderate degree of hydraulic sorting of the skeletal material. These data indicate brief transport and rapid deposition of the bonebed. There is no evidence of abrasion on a majority of the bones, and the presence of large quantities of charcoal, which is buoyant, indicate that transport was minimal. The skeletal material is associated, with no evidence of substantial weathering or of vertebrate scavenging. These phenomena reflect the rapid burial of partially dissociated carcasses.

A survivorship curve constructed for the phytosaurs, the dominant tetrapod group in the bonebed, shows a high percentage of subadult or young adult animals, who would have been the strongest members of the group. Scanning electron microscopy of the charcoalized wood demonstrates that the internal structure of the cell walls has been homogenized. The reflectance of the charcoal is significantly higher than that of other forms of coal. These two pieces of data are evidence that the wood was burned in a moderate temperature (300-450°C) ground fire. Thus, both the sedimentological and biological data from the Snyder quarry best fit the scenario of a catastrophic, Late Triassic wildfire (Zeigler, 2003).

Fossil material of several different taxonomic groups, both invertebrate and vertebrate, present in the bonebed have been studied in detail. The quarry yields a small assemblage of nonmarine invertebrates from mudstones and conglomerates a few meters above the principal bonebed (Lucas et al., 2003a). A single, incomplete conchostracan carapace from the mudstone has fine growth lines, granular sculpture, no longitudinal striae and a carapace length of ~ 6 mm. It can be tentatively assigned to the polymorphic genus *Lioestheria,* and it indicates the presence of a shallow, ephemeral pond of probable high alkalinity soon after Snyder bonebed accumulation.

The most abundant invertebrates from the Snyder quarry are unionid bivalves from a conglomerate above the main bonebed. These unionids are elongate to ovate in outline, thin shelled and have abrupt anterior ends and prominent umbonal ridges. They are tentatively assigned to *Antediplodon terraerubrae* (Meek, 1875) *sensu* Good, 1998, though we conclude that application of the name *Antediplodon* Marshall, 1929 to Chinle Group unionids is problematic. Shell shape of the Snyder quarry unionids suggests they lived in a high velocity stream, and they are preserved articulated as an allochthonous assemblage in fluvial conglomerate (Lucas et al., 2003a). *A. terraerubrae* is a common Revueltian unionid from Chinle Group strata in New Mexico, Arizona and Utah.

Mudstone above the main bonebed also yielded a decapod specimen that is wide-bodied and short-tailed, unlike other known Triassic crustaceans (Rinehart et al., 2003). This animal represents the first decapod body fossil from the Triassic of New Mexico and is the oldest eubrachyuran crab. The specimen is wide-bodied and short-tailed, unlike any of the known Triassic crustaceans, which are otherwise all of macrurous body plan (shrimp- or crayfish-like). Named *Rioarribia schrami*, n. gen. et. sp., this specimen is placed in the Eubrachyura *incertae sedis*. Previously, the oldest eubrachyurans were known from the Lower Jurassic, so *R. schrami* significantly extends the temporal range of the true crabs.

Since the first excavations, it has been obvious that the Snyder quarry represents a unique vertebrate assemblage. This assemblage includes an apparent xenacanthid shark, semionotid and redfieldiid fish, a metoposaurid amphibian, a probable procolophonid reptile, a cynodont, an apparent lepidosauromorph, abundant specimens of the phytosaur *Pseudopalatus*, the aetosaurs *Typothorax coccinarum* Cope and *Desmatosuchus chamaensis* Zeigler, Heckert and Lucas, the rauisuchian *Postosuchus* (*sensu stricto*), a sphenosuchian and theropod dinosaurs referable to *Eucoelophysis* (Zeigler et al., 2003a). Archosaurs dominate the assemblage. The xenacanth apparently pertains to the "*Xenacanthus*" *moorei* group and, if it is not a contaminant from screenwashing processes, is one of the youngest xenacanth sharks known. Both semionotid and redfieldiid fish are common in Revueltian strata in North America, and are represented by both skeletal material and abundant isolated scales. The only metoposaurid fossils recovered to date are a fragmentary, large centrum and isolated teeth that probably pertain to *Buettneria* and would thus be one of the youngest *Buettneria* records known. The possible procolophonid fossil consists of a single tooth. The cynodont is represented by an incomplete left distal humerus and may represent the oldest occurrence of a tritylodontid. The lepidosauromorph is based on an incomplete jaw fragment bearing many pleurodont teeth.

The archosaur fauna is somewhat typical of Revueltian Chinle faunas in that it includes the phytosaur *Pseudopalatus* and the aetosaur *Typothorax coccinarum*, both index taxa of the Revueltian (Norian) land-vertebrate faunachron. Rarer archosaurian taxa include the aetosaur *Desmatosuchus chamaensis*, the theropod dinosaurs, the rauisuchian (*sensu lato*) *Postosuchus* and an indeterminant sphenosuchian. The rauisuchian is represented by fragmentary postcrania that, from their disparate sizes, clearly represent at least two different individuals.

We chose to illustrate the more common vertebrates, phytosaurs and aetosaurs, from the quarry in greater detail, especially the phytosaurs, which dominate the faunal assemblage (Zeigler et al., 2003b, c). The Snyder quarry has produced the remains of several pseudopalatine phytosaurs that we refer to *Pseudopalatus buceros*. This material includes at least four complete skulls (two are fully prepared), two partial skulls, as well as numerous isolated cranial elements. These cranial elements are described and illustrated in detail and can be used to provide further evidence for sexual dimorphism in phytosaurs. We also note that taphonomic distortion of phytosaur skulls can lead to misidentification due to changes in shape of features, such as the supratemporal fenestrae, that have long been considered key to diagnosing different phytosaur genera (Zeigler et al., 2003b).

Phytosaurs are not only represented by the cranial material, but also by dozens of associated postcranial elements (Zeigler et al., 2003c). The abundance of appendicular elements in particular allow for a systematic description of phytosaur postcrania, something which is rarely seen in the literature. The majority of the phytosaurian skeletal elements in the quarry are associated with skulls, so the phytosaur postcrania are clearly those of *P. buceros*. In examining this suite of postcranial material, it becomes apparent that sexual dimorphism in *P. buceros* is restricted solely to the skull, as none of the postcrania differ substantially. There is no obvious quantitative relationship between length of any given appendicular element and its midshaft width, though it appears that the midshaft width may increase more than the length, leading to a more robust bone in adults. This thickening of the midshaft could aid in supporting the weight of an adult animal.

Indeed, phytosaurs were the largest and most common semi-aquatic predators of the Late Triassic. Although their skulls are relatively common in the fossil record, articulated, or even associated skeletons are extremely rare, so it has always been difficult to gauge just how large (mass or length) an individual phytosaur may have been. Body mass in particular is an important physiological variable, often used for the scaling of organs, biomass determination, biomechanics, and locomotion. Hurlburt et al. (2003) take advantage of phytosaurs' general similarity to extant crocodilians to attempt to reconstruct body mass and length based on measurements of the skulls and limbs of phytosaurs from the Upper Triassic Snyder and Canjilon quarries in north-central New Mexico. These quarries, in the Painted Desert Member of the Petrified Forest Formation (Revueltian: early-mid Norian) preserve catastrophic death assemblages that appear to well-represent discrete populations of phytosaurs. They also utilize a snout-vent measurement based on an articulated skeleton from the Canjilon quarry to compare the accuracy of different equations based on discrete limb elements. Body mass estimates for Snyder quarry phytosaurs range between 25 and 500 kg, with most specimens yielding estimates of approximately 200-350 kg.

The Canjilon quarry sample encompasses fewer juveniles and more robust adults, including one individual that may have weighed as much as 535 kg. From equations based on nine extant crocodilian genera, these Revueltian phytosaurs appear to have approached 4.5 m total body length for a ~ 400 kg phytosaur. The prevalence of subadult to adult phytosaurs in both quarries based on body mass estimates corroborates qualitative estimates of the population structure based on skull sizes alone, thereby reinforcing the hypothesis that both quarries are catastrophic assemblages.

The osteoderms (scutes) and postcrania of the aetosaurs are also described (Heckert et al., 2003a). The aetosaur scutes account for the single most abundant, generically identifiable vertebrate skeletal element found in the quarry. Two species of aetosaurs are known from the quarry: *Typothorax coccinarum* Cope and *Desmatosuchus chamaensis* Zeigler, Heckert, and Lucas. Both are represented entirely by postcrania, principally osteoderms (scutes), but also by isolated limb bones. Aetosaur fossils at the Snyder quarry are, like most of the vertebrates found there, not articulated. However, clusters of scutes, presumably each from a single carapace, are associated. *Typothorax coccinarum* is an index fossil of the Revueltian (early-mid Norian) land-vertebrate faunachron (lvf) and its presence was expected at the Snyder quarry, as it is known from correlative strata throughout the Chama basin locally and the southwestern U.S.A. regionally. The Snyder quarry is the type locality of *D. chamaensis*, which is considerably rarer, and presently known from only one other locality. Some specimens we tentatively assign to *D. chamaensis* resemble lateral scutes of *Paratypothorax*, but we have not found any paramedian scutes of *Paratypothorax* at the Snyder quarry, so we refrain from identifying them as *Paratypothorax*. Specimens of both *Typothorax* and *Desmatosuchus* from the Snyder quarry yield insight into the anatomy of these taxa. *Desmatosuchus chamaensis*, is clearly a species of *Desmatosuchus*, but is also one of the most distinctive aetosaurs known. Both species of aetosaur from the Snyder quarry appear to be anagenetic descendants from more primitive members of the same genus, *D. chamaensis* from *D. haplocerus* (Cope) and *T. coccinarum* from *T. antiquum* Lucas, Heckert, and Hunt.

Finally, the Snyder quarry also preserves one of the richest assemblages of Revueltian theropods, and is the second-most productive theropod locality in the Chinle Group (Heckert et al., 2003b). At least four coelophysid theropods are preserved at the Snyder quarry, based on tibiae. Most elements of these theropods are represented, including an incomplete skull and lower jaws, cervical, dorsal, sacral, and caudal vertebrae, a scapulocoracoid, ilia, ischia, femora, tibiae, a fibula, astragalocalcanea, and diverse carpals and tarsals. These specimens demonstrate that the Snyder quarry theropods pertain to the Revueltian theropod *Eucoelophysis*, only known from the type locality at Orphan Mesa 10 km to the east, and Baldwin's original collection that was described by Cope in 1881. Theropod dinosaurs at the Snyder quarry are the most abundant terrestrial predators, and outnumber rauisuchians and sphenosuchians. These theropods are, with the "Padian theropod," from the same unit in the Petrified Forest National Park and *Procompsognathus* from the Stubensandstein in Germany, part of an apparently Pangean radiation of coelophysids during Revueltian time.

Thus, this bulletin contains a wide variety of papers that relate to the many facets of research that can come from a bonebed as rich as the Snyder quarry. Both geology, in terms of lithostratigraphy and sedimentary petrology, and paleontology, invertebrate and vertebrate, are represented in this volume.

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Overview of the Snyder quarry, looking north (photograph by A.B. Heckert, September, 1999).